Precision Pointing Considerations for Long-Distance Free-Space Optical Communications

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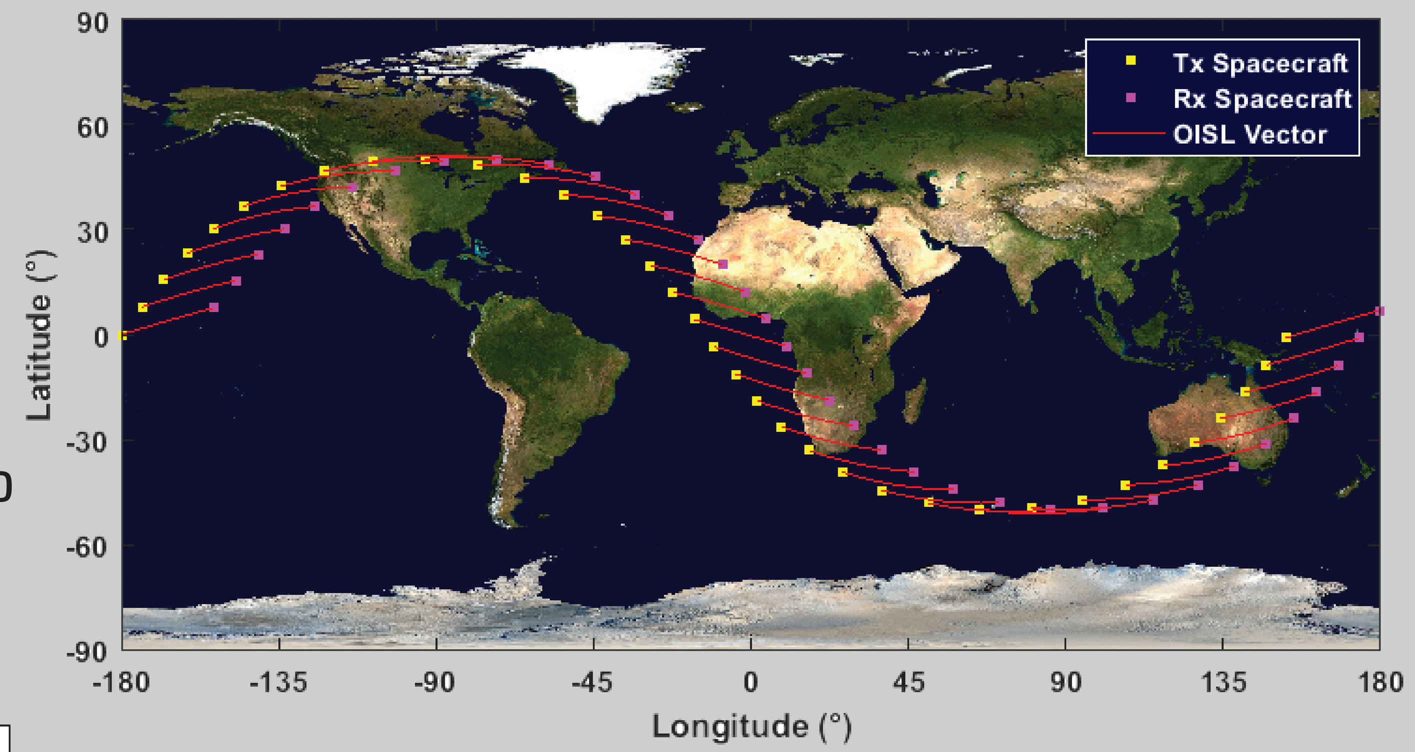
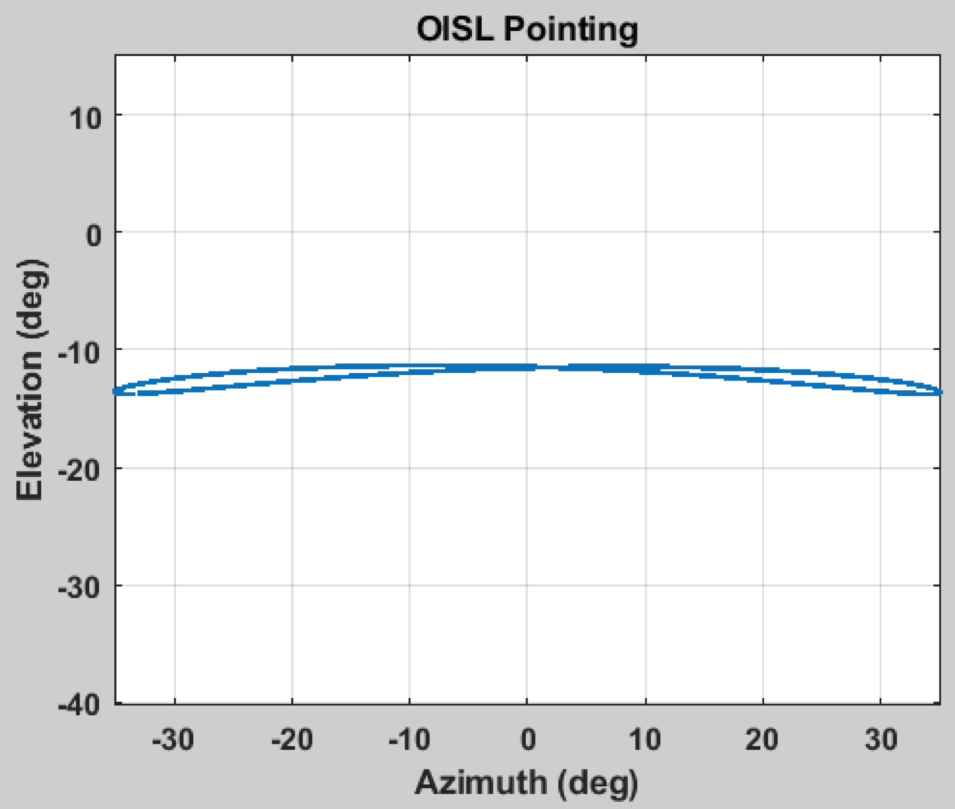
I. Introduction & Background

- Increased pointing accuracy improves throughput quadratically, whereas increased laser power only increases throughput linearly
- With tighter Coarse Pointing Assembly control, relieved requirements on Fine Pointing Assembly allow for higher resolution fine pointing sensor and lower power beacon laser
- Launch stress can lead to optical misalignment, so plan for contingencies with Auto-Calibrating sensor technology

II. OISL Simulation



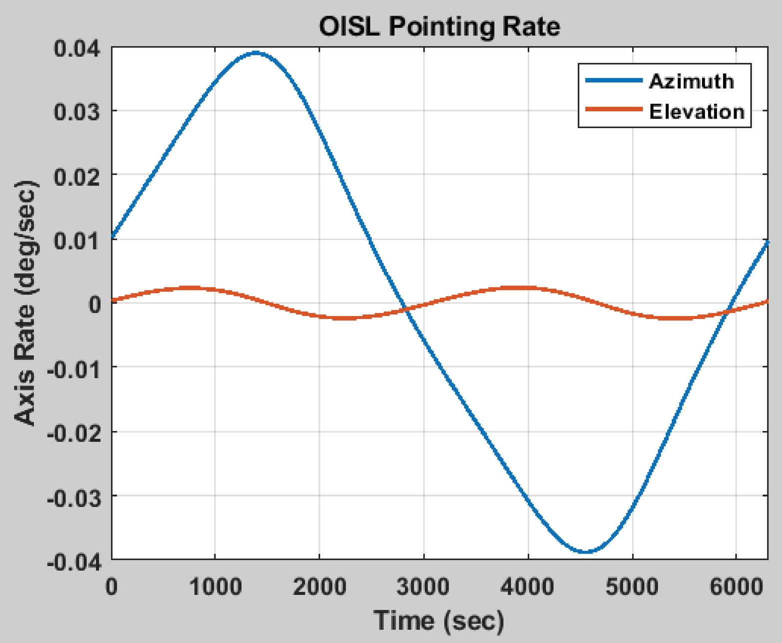
- 3-DOF Orbital Simulation to propagate Tx/Rx spacecraft orbits
- Obtain link vector and rotate into Tx spacecraft attitude frame



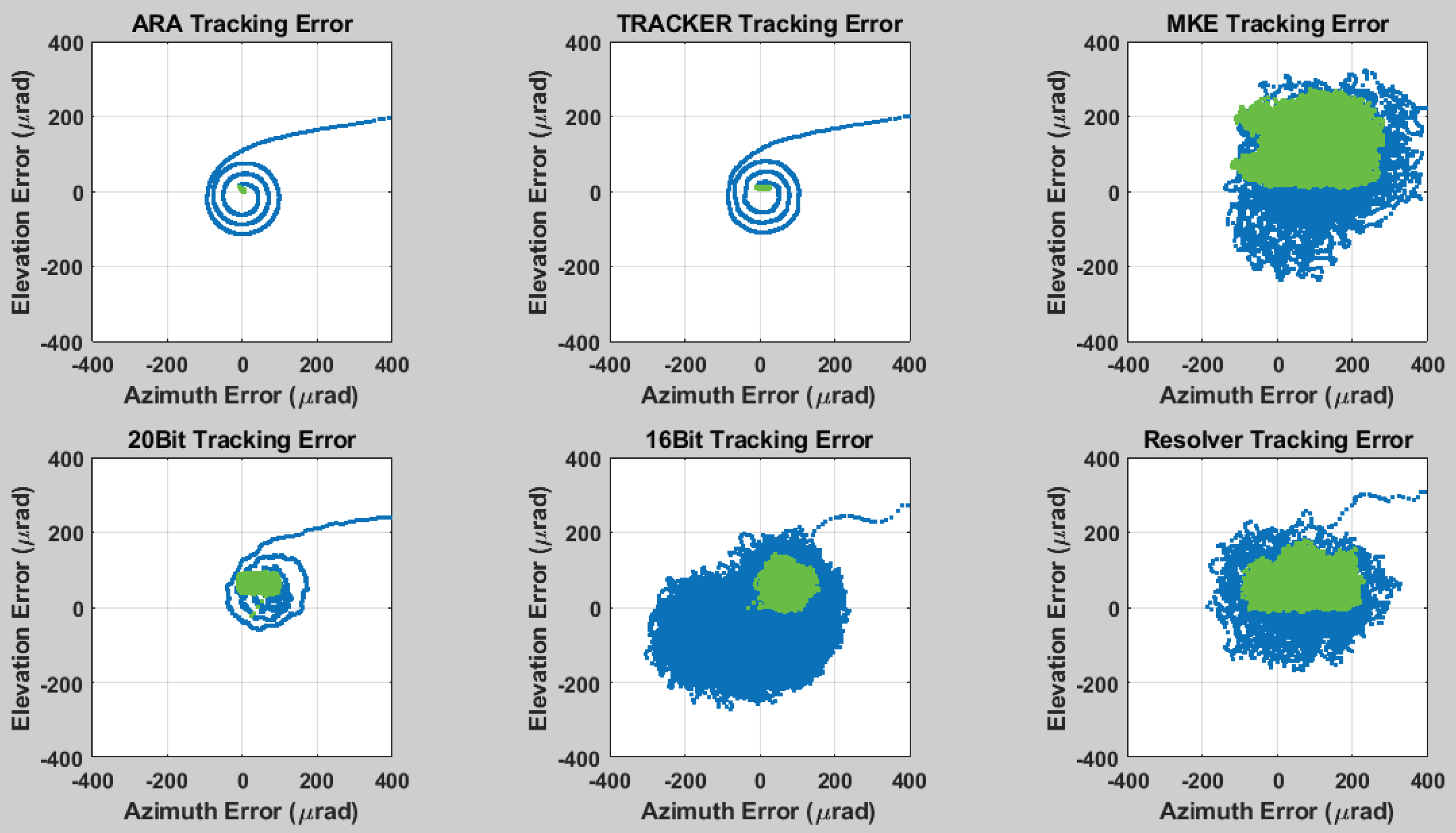
- Derive gimbal axis pointing angles (Elevation/Azimuth) from link vector
- Close PID loop with simulated sensor output around gimbal pointing angles
- Acquisition phase spirals in on uncertain Rx Spacecraft position, attempting to lock on target
- Once target acquired, track true Rx spacecraft position to best of sensor ability
- Rotary sensor simulation adds repeatable error, random noise, and quantizes the result

Manufacturer	Sensor	Full Rev. Error (μrad RMS)	Interpolated Error (μrad RMS)	ENOB (bits)	Quanta (bits)
BEI Precision	nanoSeries ARA	<4.848	0.5	26	28
BEI Precision	nanoSeries TRACKER	<12	3	24	24
BEI Precision	nanoSeries MKE	<145	30	18	24
Theoretical	20 Bit Optical Encoder	53	12.5	20	20
Theoretical	16 Bit Optical Encoder	60	30	20	16
Theoretical	16 Bit Resolver	105	72	19	16

III. Acquisition Results



- Tracking performance depends on angular rate and span
- Acquisition time reduces with accuracy/precision
- Lower precision sensors "luck" into target acquisition, need higher disparity spiral passes
- 16-Bit and 20-Bit encoders have similar overall error, but lower quantization has drastic effect on acquistion
- Interpolation error is critical for highly interpolated sensors, requires scrutinizing tests

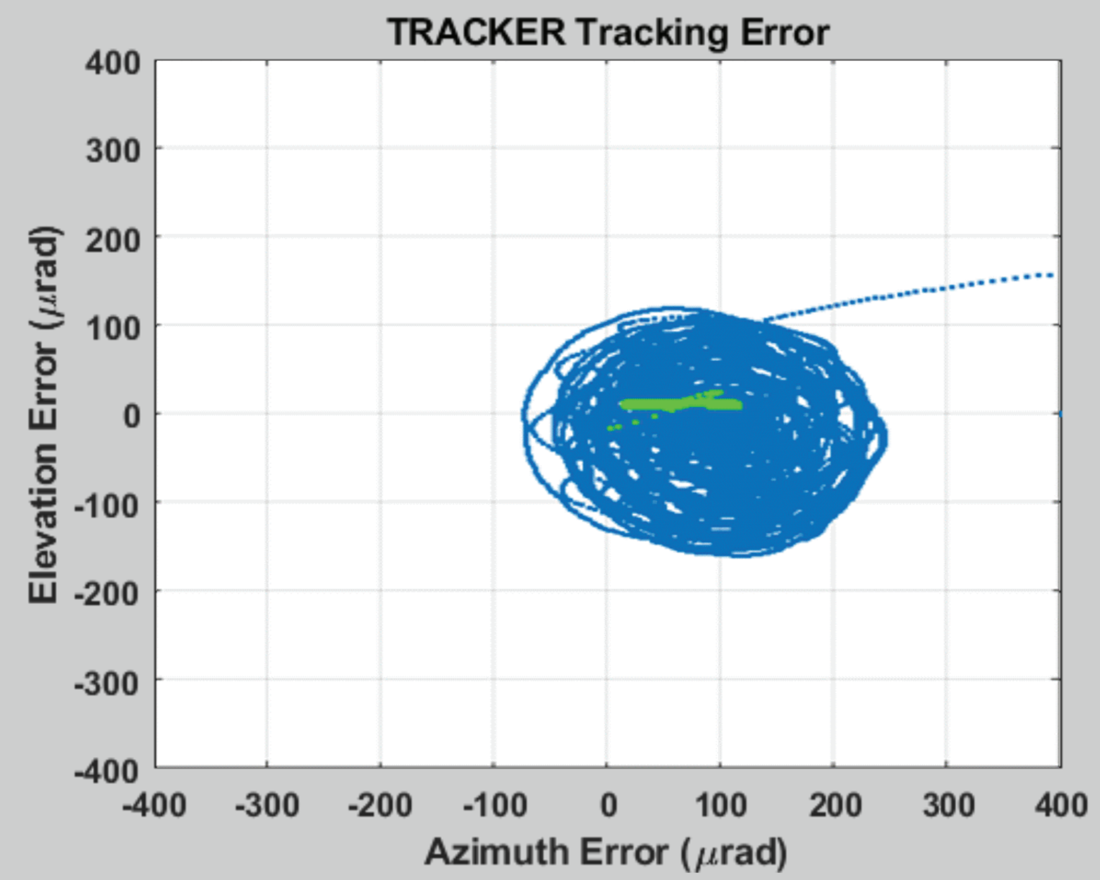


Acquisition phase in Blue, Tracking phase in Green

Sensor:	ARA	TRACKER	MKE	20 Bit	16 Bit	Resolver
Acquisition Time (sec)	91.5	93.0	2226.9	171.5	4288.4	1055.7
Az. Jitter after Acquisition (1-σ μrad)	1.176	5.559	71.942	24.163	21.123	58.520
El. Jitter after Acquisition (1-σ μrad)	0.514	1.437	61.647	11.282	24.038	29.877

IV. Design Considerations

- Rigors of launch can perturb optical/mechanical alignment and shift axes of rotation
- Boresight errors can occur, but also interpolation error due to angular sensor misalignment
- Spindle runout increase of 5 microns shown below, disabling acquistion capability



- Must have contingencies in place to account for inaccuracies
- In-situ self calibration sensors can recover from launch disturbances and axes shifts
- Value added spindle monitoring feature (Alignment Mode) can reduce troubleshooting time